The relationship between economic growth and energy consumption in Vietnam: a panel data analysis of Vietnamese cities

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The relationship between economic growth and energy consumption in Vietnam: a panel data analysis of Vietnamese cities

Pham Thi Ha [†]

This paper empirically examines the direction of causality and sign (in the panel sense) between energy consumption (EC) including coal, oil, and electricity and the gross-domestic product (GDP) for total 63 provinces in Vietnam between 2000 and 2013. Results reveal long-run stable equilibria in these cities, while the EC brings about a positive impact on GDP, and the usage of diesel contributes to economic growth more than the usage of coal and electricity in Vietnam. In the short-run, Granger causality tests reveal causality runs from GDP to EC, indicating that energy consumption is determined by economic growth. The research results support conservation hypothesis; thus, Vietnamese government can pursue the conservation energy policies that aim at curtailing energy use for environmental friendly development purposes.

Keywords: economic growth, energy consumption, coal, diesel, electricity, causality

1. Introduction

In 1986, after domestic policies proved ineffective in stimulating economic growth, the Sixth Congress of the Communist Party of Vietnam cast off the soviet model of central economic planning, and Vietnam began to embark upon reforms transitioning it to a social oriented market economy. The end of the Vietnam – Cambodian conflict in the early 1990s accelerated this process. As Vietnam devalued its currency and decontrolled most prices, a U.S. trade embargo was lifted, the country reestablished formal relations with China and member countries of the Association of Southeast Asian nations, and it obtained access to concessional international finance.

Those actions bore fruit, Vietnam, now a nation of 97 million people (based on the latest United Nations estimates), has for the past 15 years seen dizzying GDP growth at an average annual rate of 7%. In 2011, despite the global economic slowdown, the country recorded a 6.5% of GDP increase, making the 35th largest economy in the world, according to Goldman Sachs. However, like other

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countries in the world, this growth is usually accompanied by the significant increase in energy consumption (EC) and environmental problems. Over the past decades, consumption of energy in Vietnam increased tremendously in accordance with the rapid development of the Vietnamese economy towards industrialization and economic reform in catching – up with the global economy. The per capita energy consumption in Vietnam also increased by 9.3% per annum from 1990 to 2007; in addition, the total energy consumption in Vietnam is projected to increase from 55.6Mtoe in 2007 to 146 Mtoe in 2025. Industrial growth has been one key driver of Vietnam's increasing energy consumption. Industrial energy consumption grew from 8356 kTOE in 2001 to 18181 kTOE in 2001 almost 2.1 times in just 10 years. During the period of 2001 – 2011, the average growth rate of energy consumption by industry sector was 7.2% per year. Since industry is the most energy intensive main economic sector, the increasing industrialization of Vietnam's economy by itself contributes to the increase in Vietnam's overall energy consumption. This impressive performance has sparked the interest among economists and policymakers to investigate whether energy consumption is the cause or effect of economic growth in Vietnam as it had direct implications on the formulation of economic and environmental policies.

2. Literature review

Recently, Ozturk (2010) and Payne (2010) devoted their efforts in reviewing the existing literature on the nexus between energy consumption and economic growth and also provided the following four competing useful hypotheses.

(i) No causality between energy consumption and economic growth reveals the existence of a neutrality hypothesis, stating that both energy usage and economic output are not mutually associated with each other. This further indicates that the adoption of energy conservation policies related to energy usage for the purpose of reducing CO_2 emissions will not undermine the pace of economic growth. The studies support this hypothesis such as, Huang et al (2008) for low income countries, Masih et al (1996) for Malaysia, Singapore and Philippine, Soyta et al (2003) for Argentina.

(ii) The growth hypothesis, which clearly indicates the unidirectional Granger causality running from energy consumption to economic growth, suggests that a country may pursue any energy conservation policy for reducing environmental pollution that will adversely affect the pace of economic growth. In this sense, it is suggested in the literature that energy reduction policy for the sake of reducing environmental pollution should be discouraged and new sources of less consuming and lower pollution energy must be explored in order to increase the pace of economic growth. Adegboye et al (2017) for Nigeria, Lee et al (2008) for 16 Asian countries, Lee (2005) for 18 developing countries, Lau et al (2011) for for 18 Asian countries, have the findings that are consistent with this hypothesis.

(iii) If Granger causality running from economic growth to energy consumption claims the existence of a conservation hypothesis, it indicates that any adoption of energy conservation policy reducing environmental pollution would not have an adverse impact on economic growth because economic growth of a country is not associated with energy consumption. Shahbaz et al (2012) for Pakistan, Thanh Binh (2011) for Vietnam, Huang et al (2008) for middle income and rich income countries, these papers reveal the evidences of this conclusion.

(iv) The feedback hypothesis exists based on the existence of bidirectional causality between energy consumption and economic growth, which argues that a rise in economic growth leads to a rise in demand for energy and therefore using energy stimulates output in the economy. Accordingly, a country's pursuit of energy conservation policy to reduce environmental pollution will have a detrimental effect on economic growth. The following studies are consistent with this hypothesis: Huang et al (2008) for middle income and rich income countries, Chang et al (2013) for Vietnam, Cheng and Lai (1997) for Taiwan, Saatci M., & Dumrul Y (2013) for Turkey, Abbasian et al (2010) for Iran.

Against the above hypotheses, there are also various existing empirical studies on the relationship between energy and consumption and economic growth that reveal mixed or inconclusive findings due to the result of various possibilities of methodological difference and the time periods, time series, and panel data used along with the country characteristics (Soytas et al 2003a, 2003b; Lee 2006, Chiou-Wei et al 2008, and etc).

Literature review on Vietnam

For the Vietnamese economy, to best of our knowledge, the empirical papers by Thanh Binh (2011), Quang Canh (2011), Loi (2012) and Tang et al (2016) appear to be the only published works that examined the energy-growth nexus in Vietnam. Based on the bivariate regression model, Quang Canh (2011) investigated the causality relationship between electricity consumption and economic growth in Vietnam during the period of 1975-2010. Loi (2012) on the other hand, examined the Granger causality relationship between energy consumption, GDP and trade in Vietnam for the period 1986-2006. Quang Canh (2011) and Loi (2012) pointed to the evidence that there is a cointegration relationship between GDP and energy consumption, coupled with a long-run causality relationship that is running from GDP to energy consumption in Vietnam. Likewise, Thanh Binh (2011) also found evidence of uni-directional Granger causality running from economic growth to energy consumption in Vietnam; however energy consumption and economic growth are not cointegrated.

In contrast, Tang et al (2016) analyses the relationship between energy consumption and economic growth in Vietnam using the neo classical Solow growth framework for the 1971-2011 period. The results confirm the existence of cointegration among the variables. In particular, energy consumption, FDI and capital stock were found to positively influence economic growth in Vietnam. The Granger causality test revealed unidirectional causality running from energy consumption to economic growth; hence, Vietnam is an energy – dependent economy and any energy or environment policy drawn up in an attempt to conserve energy will jeopardize the process of economic development in Vietnam.

In addition, there are some multi-country researches which contain Vietnam as well. Among them, the works of Chotanawat et al (2008) for over 100 countries, included Vietnamese data during 1971-2010, Chang et al (2013) for 12 Asian countries included Vietnamese data over 1970-2010, Anwar et al (2014) for 15 Asian countries included Vietnamese data for the period of 1980-2011. However, the different results are captured due to the different methods of causality study and the sensitiveness of sample period. Chotanawat et al (2008) found that energy consumption and economic are not cointegrated, but there is evidence of Granger causality running from energy consumption to economic growth; whereas Anwar et al (2014) showed the evidence of the cointegration between energy consumption and economic growth, however there is no evidence of Granger causality running from outputs to energy consumption and vice versa. Surprisingly, Chang et al (2013) revealed the outcome of feedback hypothesis for Vietnam.

This paper contributes to energy economics literature and difference from the above papers for Vietnamese economy in at least few ways. First, this study analyses the relationship between economic growth and energy consumption in Vietnam using panel data for total 63 provinces in Vietnam, for the period from 2000 to 2013. Last, energy consumption includes three most used energy, that is, coal, diesel, and electricity. Thus, it is strongly believed that the findings of this study would be a reliable and suitable basis for policymaking.

The rest of this paper is organized as follows. Section 3 discusses the theoretical framework, data and methodology in this study. The results and conclusions are presented in Section 4 and 5, respectively.

3. Methodology and data

3.1. Data sources

Annual data from 2000 to 2013 for all 63 provinces in Vietnam were utilized for the study. The energy consumption including coal, diesel and electricity, GDP, and population were obtained from the statistical yearbooks of General Statistics Office of Vietnam. Energy consumption data are reported in terms of total energy consumption for a large selection of key enterprises in each city; however the number of selected enterprises and the proportion of enterprises vary across cities. Such data cannot provide the information of total energy consumption at city-level; therefore General Statistics Office of Vietnam had to convert available energy consumption of selected enterprises to the energy consumption of all the enterprises in each city. In this study, we assumed that energy consumption per unit of industrial product is the same among cities, and total energy consumption included the most used energy: coal, diesel and electricity. Total energy consumption is then scaled by population to form per capita energy consumption. Although, some limitations exist in the emissions data; but it is only available source to arrive at the total energy consumption in each city in Vietnam.

In this study, per capita total energy consumption is expressed in terms of million Vietnam dong, and real per capita GDP is expressed in constant 2000 billions Vietnam dong; whereas per capita coal is tons, per capita diesel is 1000 litters, and per capita electricity is 1000 kwh. All variables are transformed into natural logarithms in order to reduce hetetoskedasticty.

Vietnam is composed of 63 provinces and five centrally – governed cities, which stand on the same administrative level as provinces (namely Hanoi, Ho Chi Minh City, Can Tho, Da Nang, and Hai Phong). The General Statistics Office of Vietnam further groups these provinces and cities into 6 regions: Northern midlands and mountain areas, Red river delta, North Central Coast and South Central Coast, Central Highlands, South East, and Mekong river delta. In this study, we also estimate the relationship between total energy consumption (including coal, diesel, and electricity) and economic growth in all regions.

3.2. Panel unit roots

We apply Levin at al (1993) (LLC), lm et al (1997) (IPS), Maddala and Wu (1999) (MW, ADF) and Maddala and Wu (1999) (MW, PP) panel unit root tests to check the stationarity properties of the variables. These tests apply to a balanced panel but the LLC can be considered a pooled panel unit root test, IPS represents a heterogeneous panel test and MW panel unit root test is a non-parametric test.

3.3. Panel Cointegration

We then proceed to examine whether there exists any long-run equilibrium relationship between the variables under investigation. We resort to Pedroni (1999, 2001, 2004) and Kao (1999) panel cointegration tests.

Pedroni (1999) uses the following cointegration equation:

$$GDP_{i,t} = \alpha_i+\beta_{1i}EC_{1i,t}+\cdots+\beta_{mi}EC_{mi,t}+\mu_{it} \qquad (1)$$

where GDP is real per capita GDP, and EC is per capita energy consumption including coal, diesel and electricity; subscripts i and t represent city and year, respectively. GDP and EC are assumed to be integrated of order one. The specific intercept term α_i and slope coefficients β_{1i}, β_{2i}, .. β_{mi} vary across individual members of the panel. Pedroni (1999, 2004) proposed seven different statistics to test for cointegration relationship in a heterogeneous panel. These tests are corrected for bias introduced by potentially endogenous regressors. In the presence of cross-sectional dependence, Pedroni suggests inclusion of common time dummies to eliminate this effect. Pedroni considers seven different statistics, four of which are based on pooling the residuals of the regression along the within-dimension (panel test) of the panel. The other three are based on pooling the residuals of the regression along the between-dimension (group test) of the panel. The within-dimension tests take into account common time factors and allow for heterogeneity across individuals. The between-dimension tests are the group-mean cointegration tests, which allow for the heterogeneity of parameters across individuals.

Kao (1999) proposed Dickey Fuller (DF) and ADF-type test for ε_{it}, where the null is specified as no cointegration.

3.4. Panel Fully Modified OLS (FMOLS) Estimates

If all the variables are cointegrated, the next step is to estimate the associated long-run cointegration parameters. In the presence of cointegration, the OLS estimator is known to yield biased and inconsistent results. For this reason, several estimators have been proposed. For example, Kao and Chiang (2000) argue that their parametric panel dynamic OLS (DOLS) estimator (that pools the data along the within dimension of the panel) is promising in small sample and performs well in general in cointegrated panels. However, the panel DOLS of Kao and Chiang (2000) does not consider the importance of cross-sectional heterogeneity in the alternative hypothesis. To allow for cross-sectional heterogeneity in the alternative hypothesis, endogeneity and serial correlation problems to obtain consistent and asymptotically unbiased estimates of the cointegrating vectors, Pedroni (2000, 2001) proposed the group mean fully modified OLS (FMOLS) estimator for cointegrated panels (Appendix 1).

3.5. Panel VECM causality

We estimate a panel based vector error correction model (VECM) with a dynamic error correction term based on the analysis in Holtz-Eakin et al (1988, 1989). The following VECM models are used to test the causality relation between variables:

$$\Delta GDP_{it}=\pi_{1j}+\sum_{p=1}^{m}\pi_{11ip}\Delta GDP_{it-p}+\sum_{p=1}^{m}\pi_{12ip}\ \Delta EC_{it-p}+\mu_{li}ECT_{it-1}+\upsilon_{lit} \quad (2)$$

$$\Delta EC_{it}=\pi_{2j}+\sum_{p=1}^{m}\pi_{21ip}\ \Delta EC_{it-p}+\sum_{p=1}^{m}\pi_{22ip}\ \Delta GDP_{it-p}+\mu_{2i}ECT_{it-1}+\upsilon_{2it} \quad (3)$$

Where Δ is the lag operator and p denotes the lag length. The specification in Equation (2) allows for testing the causality direction. For example, in the short - run, the EC does not Granger cause GDP where H_0: $\pi_{12ip}=0$ for all i and p, while $\mu_{1i}=0$ in equation (2). The rejection implies that EC →GDP, supporting the growth hypothesis. Similar analogous restrictions and testing procedures can be applied in testing the hypothesis that GDP does not Granger cause movement in EC, where the null hypothesis H_0: $\pi_{22ip}=0$ for all i and p, while $\mu_{2i}=0$ in equation (3).

Similarly, we estimate a panel based vector error correction model for GDP, and coal, diesel, and electricity.

$$\Delta GDP_{it}=\pi_{3j}+\sum_{p=1}^{m}\pi_{31ip}\Delta GDP_{it-p}+\sum_{p=1}^{m}\pi_{32ip}\Delta EC_{(C)it-p}+\sum_{p=1}^{m}\pi_{33ip}\Delta EC_{(D)it-p}+ +\sum_{p=1}^{m}\pi_{34ip}\ \Delta EC_{(E)it-p}+\mu_{3i}ECT_{it-1}+\upsilon_{3it} \qquad (4)$$

$$\Delta EC_{(C)it}=\pi_{4j}+\sum_{p=1}^{m}\pi_{41ip}\Delta EC_{(C)it-p}+\sum_{p=1}^{m}\pi_{42ip}\Delta GDP_{it-p}+\sum_{p=1}^{m}\pi_{43ip}\Delta EC_{(D)it-p}+ +\sum_{p=1}^{m}\pi_{44ip}\Delta EC_{(E)it-p}+\mu_{4i}ECT_{it-1}+\upsilon_{4it} \qquad (5)$$

$$\Delta EC_{(D)it}=\pi_{5j}+\sum_{p=1}^{m}\pi_{51ip}\Delta EC_{(D)it-p}+\sum_{p=1}^{m}\pi_{52ip}\Delta GDP_{it-p}+\sum_{p=1}^{m}\pi_{53ip}\Delta EC_{(C)it-p}+ +\sum_{p=1}^{m}\pi_{54ip}\Delta EC_{(E)it-p}+\mu_{5i}ECT_{it-1}+\upsilon_{5it} \qquad (6)$$

$$\Delta EC_{(E)it}=\pi_{6j}+\sum_{p=1}^{m}\pi_{61ip}\Delta EC_{(E)it-p}+\sum_{p=1}^{m}\pi_{62ip}\Delta GDP_{it-p}+\sum_{p=1}^{m}\pi_{63ip}\Delta EC_{(C)it-p}+ +\sum_{p=1}^{m}\pi_{64ip}\Delta EC_{(D)it-p}+\mu_{6i}ECT_{it-1}+\upsilon_{6it} \qquad (7)$$

Subscripts C, D and E represent coal, diesel and electricity, respectively.

4. Empirical results and discussion

4.1. Panel unit root results

Appendix 2 presents the estimated results of unit root tests at level and first difference. These results are calculated by applying panel unit root tests: LLC, LM, ADF, and PP on each selected variable without trend, with trend and without trend and intercept. Our empirical findings illustrate that all variables (without trend and intercept) are non-stationary in their level form. However, all the series are stationary at first difference. Thus, we reject the null hypothesis of non-stationary at 1% level of significance and conclude that all series are integrated of order one I(1) in the panel of 63 provinces in Vietnam.

4.2. Panel cointegration results

From the panel cointegration results in Table 1, we find pretty strong evidence to reject the null hypothesis of no cointegration for four statistics out of seven statistics provided by Pedroni (1999, 2001, 2004). For Kao (1999) panel cointegration tests, we reject the null hypothesis of no cointegration using the ADF-type statistics; this suggests that the variables in the model for all Vietnamese cities is cointegrated and move together in the long-run. Thus we find that GDP, and coal, diesel, and electricity are cointegrated in the panel setting for the same period.

At the same time, the causality relationship between per capita GDP and total energy (including coal, diesel, and electricity) is also estimated. The result of panel cointegration is reported in Table 2, and it illustrates that per capita GDP and total energy are cointegrated in the panel for the period from 2000 to 2013.

Table 1. Panel Cointegration Tests Results for GDP and coal, diesel, electricity

A: Pedroni Residual Cointegration test							
Panel cointegration statistics (within-dimension)					Group mean panel cointegration satistics (between-dimension)		
Test	Panel v-Statistic	Panel rho-Statistic	Panel PP-Statistic	Panel ADF-Statistic	Group rho-Statistic	Group PP-Statistic	Group ADF-Statistic
Statistic	-4.4443	0.4295	-6.3246	-5.4999	2.6217	-12.4895	-8.7501
P-value	1.0000	0.6662	0.0000	0.0000	0.9956	0.0000	0.0000
B: Kao Residual Cointegration test							
Test				ADF			
Statistic				-4.7378			
P-value				0.0000			

Note: Probability values are in parenthesis

Table 2. Panel Cointegration Test Results for GDP and EC

A: Pedroni Residual Cointegration test							
Panel cointegration statistics (within-dimension)					Group mean panel cointegration satistics (between-dimension)		
Test	Panel v-Statistic	Panel rho-Statistic	Panel PP-Statistic	Panel ADF-Statistic	Group rho-Statistic	Group PP-Statistic	Group ADF-Statistic
Statistic	1.787365	-5.690924	-8.44526	-5.805833	-3.1009	-9.176	-5.8497
P-value	0.0369	0.0000	0.0000	0.0000	0.0654	0.0000	0.0000
B: Kao Residual Cointegration test							
Test				ADF			
Statistic				-3.3223			
P-value				0.0004			

Note: Probability values are in parenthesis

4.3. Panel FMOLS Estimates

Having established cointegration in the long-run, we estimate the long-run parameters of the model by using the FMOLS technique. The FMOLS corrects the standard OLS for bias induced by endogeneity and serial correlation of the regressors (Lee, 2005). The elasticity of energy consumption is important for understanding the past and assessing future economic dynamics. It represents the weights with which the marginal relative changes of the energy consumption contributes to the relative change of output (Lee et al., 2008).

Table 3. FMOLS estimates

No	Provinces	Coal	Diesel	Electricity	Total energy
	Panel estimates	0.1783(8.7313)***	0.3382(10.5720)***	0.142(20.1374)***	0.4671(487.3372)***
1	Ba Ria Vung Tau	-0.0786(-0.4589)	1.4435(7.4867)***	-0.3247(-6.0604)***	0.6300(33.0145)***
2	Ho Chi Minh	-0.2819(-1.4025)	0.9024(3.8501)***	0.1942(3.4974)***	0.5135(92.2315)***
3	Binh Duong	0.1294(3.9260)***	0.3226(8.9776)***	0.1524(13.3251)***	0.4717(193.1977)***
4	Ha Noi	-0.0919(-0.394)	0.7606(3.3551)***	0.0432(0.5535)	0.4654(49.9587)***
5	Bac Ninh	0.1682(1.3601)	-0.2187(-1.4964)	0.4881(7.5238)***	0.4465(60.9784)***
6	Quang Ninh	0.1238(1.6336)	0.3890(3.9159)***	0.1407(6.4727)***	0.4826(318.1029)***
7	Da Nang	-0.1644(-1.2911)	0.7063(4.5604)***	0.1872(5.3370)***	0.4672(122.1337)***
8	Vinh Phuc	-0.0273(-0.2902)	0.1522(1.1293)	0.4413(15.1612)***	0.4609(44.7192)***
9	Can Tho	0.1348(0.5580)	-0.1414(-0.3751)	0.4996(9.7409)****	0.4730(38.6694)***
10	Hai Phong	-0.2345(-2.4996)**	0.7698(6.3679)***	0.2107(9.2318)***	0.4595(190.1404)***
11	Dong Nai	-0.0205(-0.4603)	0.2567(4.6668))***	0.2497(18.6532)***	0.4099(162.1899)***
12	Kien Giang	-0.2149(-1.2236)	1.1019(4.1135)***	0.1470(3.4660)***	0.5350(112.6909)***
13	Khanh Hoa	-0.085(-0.6178)	0.7502(4.0431)***	0.1086(2.7955)**	0.4636(105.4278)***
14	Tay Ninh	0.1537(4.0215)***	0.2065(3.7635)***	0.2534(24.8967)***	0.4751(108.1320)***
15	Long An	0.0557(0.5583)	0.5867(4.2334)***	0.0567(1.5695)	0.4489(121.0336)***
16	Hai Duong	0.3788(3.5743)***	0.2988(1.8418)*	-0.0524(-1.4233)	0.4619(72.2656)***
17	Lam Dong	0.3470(2.2094)**	0.1877(0.7969)	0.1728(3.7412)***	0.5390(150.3794)***
18	Binh Phuoc	-0.0088(-0.1232)	0.5077(4.9829)***	0.2333(11.3798)***	0.4800(155.4657)***
19	Hung Yen	0.3099(4.6418)***	0.1079(1.1297)	0.1141(4.2358)***	0.4343(387.0595)***
20	Tien Giang	0.0998(0.7428)	0.7637(3.4491)***	-0.025(-0.5904)*	0.4836(89.3027)***
21	Vinh Long	0.1304(0.3801)	0.4313(0.8607)	0.1743(1.8566)*	0.4904(85.5610)***
22	Quang Ngai	0.7716(6.3212)***	-0.6200(-3.5318)***	0.1127(2.1439)*	0.4001(98.0547)***
23	Thai Nguyen	-0.1936(-0.9235)	0.7245(2.5819)**	0.2002(3.6713)***	0.4274(116.1701)***
24	Hoa Binh	0.8822(1.6943)	-0.2787(-0.3383)	-0.0776(-0.3729)	0.5388(28.7859)***
25	An Giang	-0.3462(-2.7925)**	1.3684(7.1706)***	0.060(2.0936)*	0.4873(86.7323)***
26	Lao Cai	0.3139(4.8038)***	-0.039(-0.3863)	0.2342(12.7922)***	0.4518(99.9559)***
27	Bac Lieu	0.1061(0.7140)	0.7072(2.8889)**	0.0928(1.5953)	0.5166(77.8947)***
28	Binh Dinh	-0.051(-0.4028)	0.8053(4.1027)***	0.0706(2.1421)*	0.4591(130.6454)***
29	Ca Mau	-0.0197(-0.3179)	0.4319(4.8619)***	0.2156(14.0934)***	0.4233(118.5482)***
30	Ben Tre	-0.0852(-0.6663)	1.2334(5.3874)***	-0.0618(-1.9230)*	0.4957(71.1050)***
31	Gia Lai	-0.0071(-0.0351)	0.6427(2.1448)*	0.1686(3.00489)**	0.4766(109.4069)***
32	Soc Trang	0.2587(2.1305)**	0.4150(2.1109)**	0.0714(1.6223)	0.4866(216.0657)***
33	Binh Thuan	0.2483(2.4691)**	0.1095(0.6891)	0.2424(8.9455)***	0.4760(103.0554)***
34	Hue	-0.1927(-1.4243)	0.9318(4.2844)***	0.1318(3.4874)***	0.4534(116.4920)***
35	Phu Tho	0.0672(0.5497)	0.6545(3.5770)**	0.01453(0.4512)	0.4362(85.5264)***
36	Ninh Binh	0.1219(1.2571)	-0.1151(-0.8299)	0.4165(12.6555)***	0.4060(41.1442)***
37	Quang Nam	-0.0809(-1.3031)	0.6280(5.9710)***	0.2018(10.1982)***	0.4467(124.6739)***
38	Lang Son	0.9606(3.7843)***	-0.7261(-1.7052)	0.0708(0.6233)	0.5343(61.8495)***
39	Thai Binh	-0.1096(-0.77413)	1.1338(4.3030)***	-0.0274(-0.5776)	0.4623(93.4218)***
40	Dak Nong	0.5214(2.1188)*	-0.358(-1.1050)	0.2295(2.5856)**	0.4483(27.5354)***
41	Quang Tri	0.6266(1.8726)*	-0.3465(-0.7345)	0.1282(1.1507)	0.4591(68.4512)***
42	Ha Nam	-0.0083(0.0658)	0.4803(2.4422)**	0.1802(4.1556)***	0.4201(102.0650)***
43	Hau Giang	0.2423(1.7232)	0.2988(1.2253)	0.0812(1.5563)	0.4437(171.5863)***
44	Ninh Thuan	0.4906(1.7009)	0.1701(0.3843)	-0.0271(-0.2490)	0.4710(57.2512)***

45	Phu Yen	−0.0229(−0.1307)	0.6366(2.2399)**	0.1841(3.6683)***	0.4638(111.6279)***
46	Bac Giang	0.3231(2.2285)**	0.5681(2.1550)*	−0.1264(−2.2478)**	0.4566(53.4740)***
47	Tra Vinh	0.1559(1.4716)	0.5683(2.9425)**	0.0778(2.7491)**	0.4790(262.9061)***
48	Nghe An	0.4323(2.0445)**	0.1041(0.2973)	0.0405(0.6010)	0.4558(92.8386)***
49	Dak Lak	0.7008(7.9374)***	−1.0611(−10.4504)***	0.4668(14.5001)***	0.4063(23.6832)***
50	Nam Dinh	0.1657(0.8603)	0.6895(2.0700)*	−0.0502(−0.8510)*	0.4507(66.7026)***
51	Quang Binh	0.276(0.9384)	0.2361(0.5152)	0.1193(1.4435)	0.4543(87.9402)***
52	Dong Thap	−0.1724(−1.74948)	0.3776(2.4996)**	0.3930(15.5775)***	0.4017(32.9560)***
53	Kon Tum	−0.147(−0.5360)	0.553(1.4189)	0.3143(3.5589)***	0.4311(51.7688)***
54	Tuyen Quang	0.5423(3.3865)***	0.0628(0.1966)	0.0251(0.3856)	0.5038(94.8432)***
55	Thanh Hoa	−0.0872(−0.5420)	0.9240(3.1162)**	0.0657(1.1858)	0.4464(88.6668)***
56	Ha Tinh	0.4143(2.0961)*	0.0393(0.1061)	0.127(1.4355)	0.4715(62.6756)***
57	Bac Kan	0.9688(4.3913)***	−0.7805(−2.0961)**	0.0671(0.6707)	0.5180(71.4758)***
58	Dien Bien	0.9245(4.0788)***	−0.6048(−1.7274)	−0.0127(−0.1300)	0.4844(64.1203)***
59	Yen Bai	0.1673(0.7683)	0.4178(1.040)	0.1481(2.0601)**	0.4593(93.0919)***
60	Cao Bang	0.2798(1.4908)	0.5108(1.4313)	−0.004(−0.0742)	0.4674(82.9077)***
61	Son La	0.4690(3.9261)***	−0.2819(−1.3229)	0.2599(5.5348)***	0.4794(58.6568)***
62	Ha Giang	0.5109(2.1022)*	−0.2529(−0.5122)	0.1623(1.7706)	0.4470(55.2358)***
63	Lai Chau	0.1578(1.6106)	−0.4676(−2.1363)**	0.5959(7.5914)***	0.4377(17.9014)***

Note: The values in parentheses are the t-statistics. Asterisks ***, ** and * denote significance at 1, 5 and 10 per cent levels, respectively. The order of provinces is basing on the level of per capita GDP, from high to low.

Table 3 reports the results of the long-run estimates for 63 provinces in Vietnam and the panel estimates based on Pedroni's group mean FMOLS estimator. The panel results of the regression equation with real per capita GDP as the dependent variable illustrate that the coefficient of total energy is positive and statistically significant at 1 percent significance level. A one percent increase in energy consumption leads to around 0.47 percent increase in real per capita GDP. Specifically, 1 percent increase in coal, diesel and electricity consumption will result in rising proximately 0.18, 0.34 and 0.14 percent in real per capita GDP, respectively. This outcomes show that diesel usage contributes to the increase of outputs in Vietnam more than coal and electricity; and more energy results in greater outputs in Vietnam. This is supported by Lee (2005), Narayan and Smyth (2008), Lee and Chang (2008), and Ozturk (2010).

At city level, for total energy, all coefficients are positive and significant at 1% level, and they range from 0.4001 (Quang Ngai) to 0.6300 (Ba Ria Vung Tau). The results indicate a positive and significant relationship between EC and real per capita GDP in all cities in Vietnam. Specifically, Ba Ria Vung Tau has the highest per capita GDP in Vietnam because it is the largest exploitation of petroleum in Vietnam; therefore energy consumption here causes economic growth significantly. In contrast, energy consumption contributes least to the economic growth in Quang Ngai province. When it comes to industrial cities, say, Ho Chi Minh, Binh Duong, Ha Noi, Bac Ninh, Quang Ninh, Da Nang, Vinh Phuc, Can Tho, and Hai Phong are the group of cities which have highest per capita GDP, energy consumption only causes from 44 to 51 percent the increase in outputs. Interestingly, Dong Nai is one of the highest income provinces in Vietnam, but the coefficient of energy consumption is in the lowest group, the coefficient is 0.4099. Thus, it is suggested that the relationship between EC and GDP across provinces are statistically significant, but it changes slightly among cities due to the geography location, population, and natural resources.

For the usage of coal, 21 out of 63 cities have the positive and significant coefficients of coal: they range from 0.9688 (Bac Kan) to 0.1294 (Binh Duong). The elasticity estimates are 0.9688, 0.9606, 0. 9245, 0.8822, and 0.7716 for Bac Kan, Lang Son, Dien Bien and Quang Ngai respectively. Bac Kan, and Dien Bien are two of the poorest provinces in Vietnam; hence coal is the most crucial energy, and it contribute to the increase in economic growth significantly. The coefficients of Hai Phong and An Giang are negative and significant at 5% level; however their coefficients for other energy are positive and significant, and they are very high for diesel, they are 0.7698 and 1.3684, for Hai Phong and An Giang, respectively; whereas for electricity they are significant, and very small.

From the results in Table 3, it reveals that diesel causes the increase in Vietnamese provinces' economy when 34 elasticity estimates are positive and statistically significant. They are range from 1.4435 (Ba Ria Vung Tau) to 0.0265 (Tay Ninh). In addition, the coefficients are very high as 1.3684, 1, 2234, 1.1338, 1.1019 for An Giang, Ben Tre, Thai Binh, and Kien giang respectively. These results suggest that diesel contributes most to Ba Ria Vung Tau, An Giang, Ben Tre, Thai Binh and Kien Giang. Meanwhile, the coefficients of Dak Lak, Bac Kan, Quang Ngai, and Lai Chau are negative and significant, it suggests that in these provinces, they are reducing to consume diesel energy in production.

For electricity, 36 out of 63 coefficients are positive and significant; it reveals that electricity stimulates economic growth in majority cities in Vietnam. The highest coefficient is 0.5959 for Lai Chau province, indicating electricity contributes most to Lai Chau's outputs. It is notable that Lai Chau province has long been the poorest city, and it is the most sparsely populated in Vietnam; hence electricity plays a crucial role for economic growth in this city. The coefficients of Ba Ria Vung Tau, Bac Giang, Ben Tre, and Tien Giang are negative and statistically significant, it suggests that electricity causes economic growth negatively in these cities.

The results for economic zones are presented in Table 4. It shows that energy consumption contributes to around 60% of outputs in all regions with the coefficients ranging from 0.5810 (Central Highlands) to 0.6419 (Northern midlands and mountain areas). In Northern midlands and mountain areas, energy consumption contributes most to its output whereas this region has seven lowest GDP provinces in Vietnam. The elasticity estimates for Red River Delta and Central Highlands are the lowest, 0.5862 and 0.5810, respectively; meanwhile the coefficients for North Central Coast and South Central Coast, South East, and Mekong River Delta are around 0.62. These results are consistent with the findings at city level: there is a positive relationship between EC and GDP among regions, but the results are mixed.

Table 4.　FMOLS estimates for 6 economic zones

No	Provinces	Coal	Diesel	Electricity	Energy consumption
1	Red river delta	0.012(0.1041)	0.6074(4.7926)***	0.1494(4.1894)***	0.5862(156.6569)***
2	Northen midlands and moutain areas	-0.2648(-1.1132)	1.1996(4.1825)***	0.0885(1.3625)	0.6419(80.3159)***
3	North Central Coast and South Central Coast	-0.1183(-1.1529)	0.9149(7.6985)***	0.0923(3.1305)*	0.6141(102.0433)***
4	Central Highlands	-0.1441(-0.4018)	0.6329(1.5114)	0.3459(3.3452)***	0.5810(108.1364)***
5	South East	-0.1629(-1.867)*	1.1321(12.0013)***	-0.0518(-1.9291)*	0.6215(55.3949)***
6	Mekong river delta	-0.2209(-1.9677)*	1.05566(7.8378)***	0.1078(5258)***	0.6277(113.0477)***

Note: the values in parentheses are the t-statistics.　Asterisks ***, ** and * denote significance at 1, 5 and 10 per cent levels, respectively.　The results of unit root test and panel cointegration for 6 economic zones at Appendix 3 and 4.

For coal, all elasticity estimates are negative except for Red River Delta; however it is only significant at 10 percent for South East and Mekong River Delta.　This result reveals that the demand of coal is decreasing in provinces in South East and Mekong River Delta, and they are switching to use cleaner energy instead of using traditional energy, which causes high pollution in Vietnam.

For diesel, only the coefficient off Central Highland is insignificant, others are positive and significant at 1 %, and range from 0.6074 (Red River Delta) to 1.1321 (South East).　In Northern Midlands and Mountain Areas, Mekong River Delta, and South East, using diesel contribute more than 100 percent in GDP; whereas it is only account for 60%, 63%, and 91 % in Red River Delta, Central Highlands, and North Central Coast and South Central Coast.

The last energy group is electricity, the coefficient of Northern Midlands and Mountain areas is positive and insignificant, whereas the coefficient of it in diesel is very high (1.1996, significant at 5%), and in coal is statistically negative insignificant.　Thus in this region, the most used energy is diesel, and it contributes more than 100% to the increase of GDP.　The same pattern can be seen in South East region, and they are decreasing the demand for coal and electricity.

The opposing pattern is in Central Highlands, when electricity contributes to around 35% of outputs, and the coefficients of coal and diesel are insignificant statistically.

The coefficients of other regions are 10% approximately, and significant at 1%, indicating that electricity results in increasing around 10% of per capita GDP.

4.4. Panel Granger Causality Test Results

Once the long-run estimates have been determined, we turn to the causality linkages.　The empirical results presented in Table 5 show that for the model in equation (4), the coefficient of lagged error-correction term (ECT) is negative and significant at 1% level but with a relatively low speed of adjustment to long-run equilibrium.　Negative error correction term confirms the existence of the long-run Granger causality running from coal, diesel and electricity to outputs.　With the respect to short-run causality tests, the results of Wald test reveal that there is no Granger causality running from coal, diesel, and electricity to GDP in the short-run.

From equation (5), ECT is positive and significant at 1 percent level which suggests that income growth does not respond to coal, and there is no long run causality from income growth, diesel, and electricity to coal. Over the short period of time, there is evidence of Granger causality running from income, and diesel to coal.

The significant and negative ECT in the model of equation (6) confirms the presence of long-run causality running from income growth, coal, and electricity to diesel. In the short-run, all coefficients are significant at 1 percent level and indicate that GDP Granger causes diesel, coal Granger causes diesel, and electricity Granger causes diesel.

In the last equation, both the long-run and short-run coefficients are significant, thus indicating the acceptance of Granger causality running from income growth, coal, and diesel to electricity.

The results of equations 5, 6, and 7 illustrate that energy consumption is determined by economic growth in Vietnam, which supports the conservation hypothesis; hence, energy conservation policy will have little effect on economic growth. This pattern is similar to results from developing economies (Cheng and Lai, 1997; Ozturk, 2010, Khanh Toan et al 2009). This result can be explained that like other low income countries, the recent economic growth in Vietnam has resulted in an expansion in commercial and industrial sectors where energy is a fundamental input. In addition, higher disposable income increases demand for electronic devices for entertainment and comfort for households.

Table 6 reports the estimation of per capita GDP and total energy consumption. The ECT is negative and significant at 1 percent level in GDP equation, indicating that there is long run causality from energy consumption to GDP, and the speed of adjustment to long-run equilibrium is very slow (around 5%). Since the estimated coefficients of the explanatory variables are statistically insignificant; hence there is no short-run causality linkage from energy consumption to outputs. By contrast, in the EC equation, ECT is negative, but it is insignificant statistically; therefore there is no long run causality from GDP to EC; but there is short run causality from GDP to EC, indicating that energy consumption is determined by economic growth. This supports the above results when each kind of energy consumption is estimated separately.

Table 5. Panel Granger Causality test results

Source of causation (independent variables)					
Dependent variables	Δ lnpcgdp Short run	Δ lnpccoal	Δ lnpcdiesel	Δ lnpcelectricity	ECT Long run
Δ lnpcgdp	-	−0.0286 (0.152)	0.0356 (0.1419)	0.0043 (0.7301)	−0.0009*** [−3.8506]
Δ lnpccoal	0.3478 (0.0246)	-	−0.3502 (0.0004)	−0.0292 (0.5637)	0.2520*** [8.7916]
Δ lnpcdiesel	0.5269 (0.0001)	−0.2012 (0.0036)	-	-0.1837 (0.0000)	-0.0192*** [−4.6666]
Δ lnpcelectricity	0.7489 (0.0000)	−0.9080 (0.0000)	0.491 (0.0000)	-	−0.3267*** [−16.4674]

Note: Wald F-statistics reported with respect to short-run changes in the independent variables. ECT represents the coefficient of the error correction term. Values in ( ) are p-values and values in [ ] are t-ratios. *** Significance at 1% level.

Table 6. Panel Granger Causality test results

Source of causation (independent variables)			
Dependent variables	Δ lnpcgdp Short run	Δ lnpcec	ECT Long run
Δ lnpcgdp	- -	0.001601 (0.8641)	−0.0518*** [−7.2836]
Δ lnpcec	0.6253 0.0000	- -	−0.0149 [−1.1432]

Note: Wald F-statistics reported with respect to short-run changes in the independent variables. ECT represents the coefficient of the error correction term. Values in ( ) are p-values and values in [ ] are t-ratios. *** Significance at 1% level.

5. Concluding remarks

Using panel estimation for 63 provinces in Vietnam, this paper empirically examines the relationship between total energy consumption including coal, diesel, and electricity and GDP. We find that the variables were in a stationary fashion in their first differences or were in an I(1) process. The panel cointegration results reveal a long-run equilibrium relationship among the variables. The results of the FMOLS show that the majority of energy consumption variables have a positive sign, indicating that GDP increase leads to more energy use. When turning to the city specific coefficients, the relationship between EC and GDP across provinces is positive, and statistically significant; but it varies slightly among cities due to the geography location, population, and natural resources. This research results suggest that energy consumption is not a limiting factor for the Vietnam's economic growth, and it implies that the rise in energy prices can be a good opportunity for the economy to promote substitution and technological innovation.

From the Granger causality test, there is a short-run unidirectional causal relationship running from GDP to energy consumption. This implies that in the short-run, economic growth leads to energy consumption in Vietnam, and energy is only one of essential inputs to production in Vietnam, supporting the conservation hypothesis. This result is consistent with Quang Canh (2011), Thanh Binh (2011), and contradictory with Tang (2016) for the studies in Vietnamese economy. The results are mixed for these studies because they use different methodologies, variables as well as time series of variables in each research.

The research results support conservation hypothesis, since a high level of economic growth results in a high level of energy demand, but not vice versa. Thus, for the policy perspective, Vietnamese government can pursue the conservation energy policies that aim at curtailing energy use for environmental friendly development purposes. At the same time, the market competitiveness of traditional energy market and renewable energies could be gradually established, and improve alternative sources of energy or renewable energy such hydropower, forest and bio-mass power, wind and solar power, and geothermal power. These suggestions in line with the National Plan for Environment and Sustainable Development which aims to develop eco-friendly energy sector in Vietnam.

This study just focuses on the bivariate causality tests for energy consumption (coal, diesel, and electricity) and economic growth for 63 provinces in Vietnam during the period from 2000 to 2013. Further studies can be done by using longer time series, including more types of energy, and using either multivariate models for total energy or bivariate models for disaggregated energy consumption in industrial, residential, transport sectors.

References

1. Abbasian, E., Nazai, M., & Basrindoost., M. (2010). Energy Consumption and Economic Growth in the Iranian Economy: Testing the Causality Relationship. 5(5), 374-381.
2. Anwar, S., & Nasreen, S. (2014). Causal relationship between trade openness, economic growth and energy consumption: A panel data analysis of Asian countries. Energy Policy. 69, 82-91.
3. Chang, T., Chu, H.P., & Chen W.Y. (2013) Energy consumption and economic growth in 12 Asian countries: panel data analysis. Applied Economics Letters. 20, 282-287.
4. Chotanawat, J., Hunt, L.C., Pierse, R. (2008). Does energy consumption cause economic growth? Evidence from a systematic study of over 100 countries. Journal of Business and Economic Statistics. 10, 237-250.
5. Cheng, B.S.,& Lai, T.W. (1997). An investigation of co-integration and causality between energy consumption and economic activity in Taiwan. Energy Economics. 19, 435-444.
6. Chiou-Wei, S.Z., Chen, C.F., & Zhu, Z. (2008). Economic growth and energy consumption: evidence from linear and nonlinear Granger causality. Energy Economics. 30, 3063-3076.
7. General Statistical Office. (2013). Statistical Yearbook 2012. Hanoi: Statistical Publishing House, Vietnam.

8. General Statistical Office. Statistical Yearbook 1994-2015. Hanoi: Statistical Publishing House, Vietnam.
9. General Statistical Office. http://www.gso.gov.vn/Default.aspx?tabid=706&ItemID=13412
10. Holtz-Eakin, D., Newey, W., & Rosen, H. (1988). Estimating vector autoregressions with panel data. Economietrics. 56, 1371-1395.
11. Holtz-Eakin, D., Newey, W., & Rosen, H. (1989). The revenues-expenditure nexus: evidence from local government data. International Economic Review. 30, 415-429.
12. Huang, B., M.J. Hwang, & C.W, Yang. (2008). Causal relationship between energy consumption and GDP revisited: a dynamic panel data approach. Ecological Economics. 67. 41-54.
13. International Energy Agency: https://www.iea.org/countries/Vietnam/
14. Im, K.S., Pesaran, M.H., & Shin, S. (1997). Testing for unit roots in heterogenous panels. Working Paper No.9526, Department of Applied Economics, University of Cambirdge.
15. Kao, C. (1999). Spurious Regression and Residual – Based Tests for Cointegration in Panel data. Journal of Econometrics. 90, 1-44.
16. Kao, C., & Chiang, M.H. (2000). On the estimation and inference of a cointegrated regression in panel data. In: Baltagi B, H. (Ed). Advances in Econometrics: Nonstationary Panels, Panel Cointegration and Dynamic Panels. 15, 179-222.
17. Lau, E., Chye, X.H., & Choong, C.K. (2011). Energy – Growth Causality: Asian Countries Revisted. International Journal of Energy Economics and Policy. 1(4), 140-149.
18. Levin, A., Lin, C.F., Chu, C.S.J. (2002). Unit root test in panel data: Asymptotic and finite sample properities. Journal of Econometrics. 108. 1-24.
19. Lee, C.C. (2005). Energy consumption and GDP in developing countries: a cointegrated panel analysis. Energy Economics. 27, 415-427.
20. Lee, C.C. (2006). The causality relationship between energy consumption and GDP in 11 countries revisited. Energy Policy. 34, 1086-1093.
21. Lee, C. C., & Chang, C. P. (2008). Energy consumption and economic growth in Asian economies: a more comprehensive analysis using panel data. Resource and Energy Economics. 30, 50-65.
22. Lee, C.C., Chang, C.P., & Chen, P.F. (2008). Energy-income causality in OECD countries revisited: the key role of capital stock. Energy Economics. 30, 2359-2373.
23. Loi, ND. (2012). Energy consumption and economic development: Granger causality analysis for Vietnam. Vietnam development and polices research centre (DEPOCEN). Working paper no.14: 2012, 1-24.
24. Maddala, G.S., & Wu, S. (1999). A comparative study of unit root tests with panel data and a new simple test. Oxford Bulltetin of Economics and Statistics. 61, 631-652.
25. Ministry of Natural Resources and Environment. (2014). National strategy on environmental protection to 2020 and vision to 2030. Decision No.166/QD-TTg dated 21 January 2014, Hanoi, Vietnam.
26. Masih, A.M.M., & Masih, R. (1996). Energy consumption, real income and temporal causality: results from a multi-country study based on cointegration and erro-correction modeling techniques. Energy Economics. 18, 165-183.
27. Nasreen, S., & Anwar, S. (2014). Causal relationship between trade openness, economic growth and energy consumption: A panel data analysis of Asian countries. Energy Policy. 69, 82-91.
28. Narayan, P.K., & Smyth, R. (2008). Energy consumption and real GDP in G7 countries: New evidence from panel cointegration with structural breaks. Energy Economics. 30, 2331-2341.
29. Ozturk, I. (2010). A literature survey on energy – growth nexus. Energy Policy. 38, 340-349.
30. Ozturk, I., & Acaravci, A. (2010). The causal relationship between energy consumption and GDP in Albania, Bulgaria, Hungary and Romania: Evidence from ADRL bound testing approach. Applied Energy. 87, 1938-1943.
31. OECD: https://www.iea.org/countries/Vietnam/
32. Payne, J.E. (2010). Survey of the International evidence on the causal relationship between energy consumption and growth. Journal of Economic Studies. 37, 53-95.

33. Pedroni, P. (1999). Critical values for cointegration tests in heterogeneous panels with multiple regressors. Oxford Bulletin of Economics and Statistics. 61, 653-670.
34. Pedroni, P. (2000). Fully modified OLS for heterogeneous cointegrated panels. Advances in Econometrics. 15, 93-130.
35. Pedroni, P. (2001). Purchasing power parity tests in conintegrated panels. The Review of Economics and Statistics. 83, 727-731.
36. Pedroni, P. (2004). Panel cointegration: Asymptotic and finite sample properities of pooled time series tests with an application to the PPP hypothesis. Econometric Theory. 20, 597-625.
37. Saatci, M., & Dumrul, Y., (2013). The relationship between Energy consumption and Economic growth: evidence from a structural break analysis for Turkey. International Journal of Energy Economics and Policy. 1(3), 20-29.
38. Shahbaz, M,. & Feridum, M. (2012). Electricity consumption and economic growth empirical evidence from Pakistan. Qual Quant. 46, 1583-1599.
39. Soytas, U., & Sari, R. (2003a). Energy consumption and GDP: causality relationship in G-7 countries and emerging markes. Energy Economics. 25, 33-37.
40. Soytas, U., & Sari, R. (2003b). Energy consumption and GDP: causality relationship in G-7 countries and emerging markes. Energy Economics. 25, 33-37.
41. Quang Canh, L. (211). Electricity Consumption and Economic Growth in Vietnam: A Cointegration and Causality Analysis. Journal of Economics and Development. 3(13), 24-36.
42. Tang, C.F., & Tan, B.W. (2015). The impact of energy consumption, income and foreign direct investment on carbon dioxide emissions in Vietnam. Energy, 79, 447-554.
43. Tang, C.F., Tan, B.W, & Ozturk, I. (2016). Energy consumption and economic growth in Vietnam. Renewable and Sustainable Energy Reviews. 54, 1506-1514.
44. Thanh Binh, P. (2011). Energy Consumption and Economic Growth in Vietnam: Threshold Cointegration and Causality Analysis. International Journal of Energy Economics and Policy. 1(1), 1-17.
45. Khanh Toan, P., Bao, N.M., & Dieu, N.H. (2011). Energy supply, demand, and policy in Vietnam, with future projection. Energy Policy. 39. 6814-6826.

Appendix 1 Fully Modified OLS Estimates

Following Pedroni (2001), the FMOLS technique generates consistent estimates in small samples and does not suffer from large size distortions in the presence of endogeneity and heterogeneous dynamics. The panel FMOLS estimator of coefficient β is defined as:

$$\hat{\beta}=\mathrm{N}^{-1}\sum_{i=1}^{N}\left(\sum_{t=1}^{T}(y_{it}-\bar{y})^{2}\right)^{-1}\left(\sum_{t=1}^{T}(y_{it}-\bar{y})z_{it}^{*}-\mathrm{T}\hat{\eta}_{i}\right. \qquad (5)$$

Where $z_{it}^{*}=(z_{it}-\bar{z})-\frac{\widehat{L_{211}}}{\widehat{L_{221}}}\Delta y_{it}$, $\hat{\eta}_{i}=\hat{\Gamma}_{21i}+\hat{\Omega}^{0}{}_{21i}-\frac{\widehat{L_{211}}}{\widehat{L_{221}}}(\hat{\Gamma}_{22i}+\hat{\Omega}^{0}{}_{22i})$ and $\hat{L}_{i}$ is a lower triangular decomposition of $\hat{\Omega}^{0}{}_{i}$. The associated t-statistics give:

$$t_{\hat{\beta}^{*}}=\mathrm{N}^{-1/2}\sum_{i=1}^{N}t_{\hat{\beta}^{*},}\ i \text{ where } t_{\hat{\beta}^{*},}\ i=(\hat{\beta}^{*}{}_{i}-\beta_{0})\left[\hat{\Omega}^{-1}{}_{11i}\sum_{t=1}^{T}(y_{it}-\bar{y})^{2}\right]^{1/2}$$

Appendix 2: Panel unit root test results

Variables	At level						At first difference					
	without trend	P-value	with trend	P-value	None	P-value	without trend	P-value	with trend	P-value	None	P-value
LLC test												
lnpcgdp	−5.2929	0.0000	2.62792	0.9957	35.6176	1.0000	−13.3769	0.0000	−15.2517	0.0000	−5.1831	0.0000
lnpccoal	−13.0374	0.0000	−0.91561	0.1799	12.0912	1.0000	−20.9569	0.0000	−29.918	0.0000	−18.6355	0.0000
lnpcdiesel	−5.86627	0.0000	0.88398	0.8116	13.3046	1.0000	−19.2483	0.0000	−17.9885	0.0000	−17.5637	0.0000
lnpcelectricity	−5.60241	0.0000	−6.52916	0.0000	25.9589	1.0000	−27.4478	0.0000	−22.9338	0.0000	−7.71016	0.0000
lnpcec	−14.103	0.0000	8.19972	1.0000	20.1922	1.0000	−17.9095	0.0000	−23.3579	0.0000	−8.84995	0.0000
Im, Pesaran and Shin W-stat												
lnpcgdp	5.24783	1.0000	4.81927	1.0000			−8.84209	0.0000	−6.04334	0.0000		
lnpccoal	−4.82903	0.0000	8.54622	1.0000			−16.4893	0.0000	−22.9104	0.0000		
lnpcdiesel	−0.84299	0.1996	1.83840	0.9670			−19.8213	0.0000	−20.5063	0.0000		
lnpcelectricity	2.83352	0.9977	−1.84543	0.0325			−22.7641	0.0000	−17.9888	0.0000		
lnpcec	−3.68979	0.0001	11.4239	1.0000			−17.0695	0.0000	−22.5398	0.0000		
ADF - Fisher Chi-square												
lnpcgdp	72.9861	1.0000	85.6449	0.9977	12.3960	1.0000	301.239	0.0000	234.047	0.0000	193.088	0.0001
lnpccoal	184.727	0.0005	42.9294	1.0000	19.6504	1.0000	499.883	0.0000	601.457	0.0000	499.232	0.0000
lnpcdiesel	141.046	0.1700	188.561	0.0003	55.7466	1.0000	610.601	0.0000	559.950	0.0000	453.768	0.0000
lnpcelectricity	61.3189	1.0000	157.076	0.0316	11.1856	1.0000	654.756	0.0000	508.138	0.0000	215.622	0.0000
lnpcec	165.320	0.0108	67.9562	1.0000	57.8794	1.0000	574.477	0.0000	626.158	0.0000	257.923	0.0000
PP - Fisher Chi-square												
lnpcgdp	57.0448	1.0000	91.1221	0.9917	2.49014	1.0000	336.314	0.0000	279.002	0.0000	215.856	0.0000
lnpccoal	328.777	0.0000	64.8364	1.0000	7.11376	1.0000	586.849	0.0000	926.511	0.0000	756.685	0.0000
lnpcdiesel	167.761	0.0076	252.366	0.0000	8.63389	1.0000	821.480	0.0000	763.668	0.0000	891.430	0.0000
lnpcelectricity	46.2088	1.0000	166.999	0.0085	0.76227	1.0000	812.034	0.0000	779.158	0.0000	579.350	0.0000
lnpcec	173.189	0.0034	130.039	0.3845	1.96616	1.0000	804.595	0.0000	1025.67	0.0000	671.399	0.0000

Appendix 3: Panel unit root test results for 6 economic zones

Variables	At level						At first difference					
	without trend	P-value	with trend	P-value	None	P-value	without trend	P-value	with trend	P-value	None	P-value
LLC test												
lnpcgdp	-1.03469	0.1504	1.47507	0.9299	18.3298	1.0000	-3.95008	0.0000	-4.2421	0.0000	-1.56448	0.0589
lnpccoal	-4.32618	0.0000	-0.28389	0.3882	4.09107	1.0000	-4.14669	0.0000	-7.74171	0.0000	-5.53895	0.0000
lnpcdiesel	-2.18515	0.0144	-0.70214	0.2413	6.26918	1.0000	-6.73494	0.0000	-6.01374	0.0000	-6.45931	0.0000
lnpcelectricity	-2.59774	0.0047	-0.96292	0.1678	9.70947	1.0000	-8.39302	0.0000	-8.25103	0.0000	-1.7532	0.0398
lnpcec	-5.22543	0.0000	3.85924	0.9999	6.27014	1.0000	-3.92299	0.0000	-10.5234	0.0000	-2.06368	0.0195
Im, Pesaran and Shin W-stat												
lnpcgdp	2.02635	0.9786	1.41776	0.9219			-3.2968	0.0005	-1.56488	0.0588		
lnpccoal	-1.79572	0.0363	3.05917	0.9989			-2.68861	0.0036	-5.09181	0.0000		
lnpcdiesel	-0.29575	0.3837	0.36052	0.6408			-5.81645	0.0000	-4.25965	0.0000		
lnpcelectricity	0.62640	0.7345	0.07746	0.5309			-6.81306	0.0000	-5.71291	0.0000		
lnpcec	-1.47867	0.0696	4.19241	1.0000			-3.3925	0.0003	-7.91184	0.0000		
ADF - Fisher Chi-square												
lnpcgdp	3.11231	0.9947	4.47255	0.9733	0.04723	1.0000	30.7527	0.0021	18.7813	0.0939	17.0253	0.1486
lnpccoal	19.2725	0.0822	2.35620	0.9986	1.12623	1.0000	28.3783	0.0049	43.4917	0.0000	44.7432	0.0000
lnpcdiesel	10.3278	0.5872	9.77662	0.6356	0.89195	1.0000	50.7674	0.0000	37.9390	0.0002	65.9727	0.0000
lnpcelectricity	5.81116	0.9253	10.2448	0.5945	0.02674	1.0000	59.5060	0.0000	48.6572	0.0000	12.7332	0.3887
lnpcec	18.2329	0.1088	2.12549	0.9992	0.90682	1.0000	35.2416	0.0004	62.7923	0.0000	14.3103	0.2813
PP - Fisher Chi-square												
lnpcgdp	3.11384	0.9947	5.00230	0.9579	0.07199	1.0000	31.5790	0.0016	19.9355	0.0683	18.9474	0.0898
lnpccoal	30.2906	0.0025	2.95153	0.9959	0.54479	1.0000	38.8893	0.0001	62.9225	0.0000	57.4118	0.0000
lnpcdiesel	18.0605	0.1139	11.4143	0.4938	0.51722	1.0000	48.9164	0.0000	39.7248	0.0001	64.3104	0.0000
lnpcelectricity	5.99574	0.9163	10.0681	0.6100	0.03156	1.0000	70.9279	0.0000	72.8067	0.0000	41.9299	0.0000
lnpcec	17.3520	0.1368	5.62386	0.9338	0.09903	1.0000	55.7597	0.0000	72.1845	0.0000	46.6072	0.0000

Appendix 4. Panel Cointegration Tests Results for 6 economic zones

A: Pedroni Residual Cointegration test							
	Panel cointegration statistics (within-dimension)				Group mean panel cointegration satistics (between-dimension)		
Test	Pane v-Statistic	Panel rho-Statistic	Panel PP-Statistic	Panel ADF-Statistic	Group rho-Statistic	Group PP-Statistic	Group ADF-Statistic
Statistic	-1.693871	-0.522619	-2.691377	-1.669943	0.966252	-2.962261	-2.572379
P-value	0.9549	0.3006	0.0036	0.0475	0.8330	0.0015	0.0051
B: Kao Residual Cointegration test							
Test	ADF						
Statistic				-2.015454			
P-value				0.0219			

Note: Probability values are in parenthesis